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(12) (19) (CA) **Demande-Application**

(21) (A1) **2,307,251**
(22) 2000/04/27
(43) 2000/10/30

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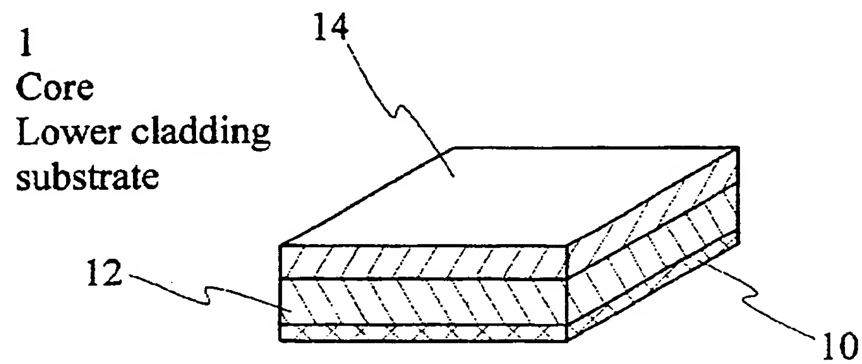
(51) Int.Cl.[7] G02F 1/01
(30) 1999/04/30 (2,271,159) CA

(54) **ATTENUATEUR OPTIQUE A RETROREFLEXION**
(54) **BACK-REFLECTING OPTICAL ATTENUATOR**



(57) An optical device is disclosed that serves as a variable attenuator in one mode of operation or which can serve as a device for testing a network path. A polymer region is directly coupled to an end of an optical fibre or is coupled directly between two optical fibres. A heater is provided to vary the refractive index of the polymer which results in a refractive index difference between the polymer and the glass cores the polymer is coupled with.

Abstract of the Disclosure

An optical device is disclosed that serves as a variable attenuator in one mode of operation or which can serve as a device for testing a network path. A polymer region is directly coupled to an end of an optical fibre or is coupled directly between two optical fibres. A heater is provided to vary the refractive index of the polymer which results in a refractive index difference between the polymer and the glass cores the polymer is coupled with.

Back-reflecting Optical Attenuator

Field of the Invention

This invention relates to an optical attenuator and more specifically to an optical attenuator, which controllably attenuates an optical signal launched into an optical waveguide such as an optical fibre.

Background of the Invention

Optical attenuators are well known. For example United States Patent 5,915,063 in the name of Colbourne et al. describes an attenuator that attenuates an optical signal variably by controllably tilting a reflector to couple the beam between two optical fibres. Although this invention works well, and provides a required functionality, there are instances where it is desired to provide an attenuator wherein light transmitted could be interrupted and reflected partially upon providing control signals. An example of this is in an optical-time domain reflectometry application. In other applications it is desired to provide a termination wherein light can either be extinguished, or wherein a signal can be reflected backwards from towards it source, either fully or partially. It is also desired to provide an inexpensive, inline optical attenuator which requires no power when in a non-attenuating mode and which requires little power when attenuation is desired.

Devices are known that can be used, in a wavelength dependent manner, to reflect signals variably, in dependence upon control signals. For example, a Bragg grating will reflect light corresponding to a channel having a certain central wavelength; Furthermore, Bragg gratings can to some extent be tuned, so that the central wavelength varies by heating or stretching the grating. However, Bragg gratings, are costly to manufacture, are highly wavelength dependent, and require photosensitive optical fibre to write the grating therein; as well, the tuning range is quite limited.

It is an object of this invention, to provide a reflective attenuator that is inexpensive to manufacture, and is substantially wavelength insensitive.

It is also an object of this invention to provide an attenuator that can be switched on or off in dependence upon a control signal and that can be disposed between two optical fibres without considerable signal loss.

It is also an object of this invention to provide a device that is normally in a light transmissive mode of operation, and which switches into a reflective mode of operation when power is applied, thereby requiring no power or little power when the device is in its normal or usual pass-through mode.

It is an object of this invention, to provide a waveguide that uses the beneficial characteristics of inorganic glass such as silica, and as well the beneficial characteristics of polymer waveguides, while minimizing the unwanted characteristics of these materials.

It is an object of this invention to use the different properties of polymer and glass to an advantage in a synergistic manner.

For example, it is desired to have a optical waveguide with an active region which is highly thermo-optic active, so that it may be switched, attenuated, or modulated with low power. Notwithstanding, it is desired to have an optical waveguide that under normal transmission is highly transparent, i.e. has little signal power loss. Yet still further, it is desired to have a waveguide wherein the refractive index can be changed relatively efficiently and significantly with minimal power. And yet still further, it is desired to have a waveguide with two different regions, having guided light transmitting cores that have relatively different refractive indices, yet that can be modified by the application of a suitable energy, to lessen or obviate the refractive index difference between the two regions. The latter being significantly useful in optical coupling applications such as this invention.

Summary of the Invention

In accordance with the invention, an optical device is provided comprising:
waveguide, having a glass core and a cladding, the waveguide having at an end thereof region of polymer optically and physically coupled with the glass core; and,
means for varying the refractive index of the polymer in dependence upon a control signal.

In accordance with the invention, there is further provided, a device for allowing light to propagate therethrough in a first transmissive mode of operation and for at least partially reflecting light launched therein in a second at least partially reflecting mode of operation comprising:
a first and a second optical fibre;
a polymer region disposed therebetween and coupled with an end of each of the first and second optical fibres, and
means for controllably changing the refractive index of the polymer region to switch between the first mode of operation and the second mode of operation.

Brief Description of the Drawings

Fig. 1 is an isometric view of a two layered planar structure on a flat substrate serving as a base for fabricating a waveguide device;
Fig. 2 is an isometric view of the device shown in Fig. 1 including a metal mask disposed atop an upper layer for use in providing grafted parts;
Fig. 3 is an isometric view of the device shown in Fig. 2 wherein three grafting parts are shown after removing unmasked material around the parts;
Fig. 4 is an isometric view of the device shown in Fig. 3 including an additional spin coated layer;

Fig. 5 is an isometric view of the device shown in Fig. 5 having a mask upon the grafting parts and adjacent polymer material for form a longitudinal core section;

Fig. 6 is an isometric view of the device shown in Fig. 5, wherein the composite core with grafted sections are shown after removal of the unmasked surrounding material, awaiting a final upper cladding layer to be spin-coated thereon;

Fig. 7 is an isometric view of a waveguide device having a grafted core surrounded by a cladding;

Figs 8 through 11 are isometric views of a grafting process for providing polymer core sections into a silica core waveguide;

Figs. 12a through 12d illustrate different etch back states;

Fig. 13 is a cross sectional view from a prior art patent EP 0707113A1 in the name of Bosc et al assigned to France Telecom wherein a planar waveguide is disclosed having silica core and a polymer cladding region.

Fig. 14 is an isometric view of a hybrid core of an optical waveguide in accordance with an embodiment of the invention;

Fig. 15 is an isometric view of an alternative hybrid core of an optical waveguide in accordance with an embodiment of the invention;

Fig. 16 is a side view of an optical fibre having a polymer end contained within a container coupled with a cleaved end of the fibre, wherein a heater is thermally coupled to the end;

Fig. 17 is a side view of an alternative embodiment wherein a region of polymer is disposed between two optical fibre ends;

Fig. 18 is a diagram of an optical network having modules at ends thereof for testing the network; and,

Fig. 19 is side view of an embodiment similar to that of Fig. 17 wherein expanded core optical fibre is used.

Detailed Description

Referring now to the table below, some properties of various materials used in photonics are shown.

Typically, optical fibers comprise a light-carrying core, for example an inorganic glass

Property		Fused silica	BK7 glass	Sapphire	Calcium Fluoride	Silicon	Polymer glass	Polymer rubber
refractive index	n	1.4	1.5	1.7	1.4	3.5	1.4-1.6	1.4-1.6
thermooptic coeff.	dn/dT (10^{-6} K^{-1})	10	1.6	14	-9	200	-100	-500
expansion coeff.	(dl/l)/dT (10^{-6} K^{-1})	0.5	7	8	19	3	100	300
thermal conductivity	λ ($Wm^{-1}K^{-1}$)	1.4	1	22	10	84	0.2	0.2
Young's Modulus	E (GPa)	73	81	345	76	131	2	0.001
Poisson ratio	ν	0.2	0.2	0.2	0.2	0.3	0.4	0.5

such as fused silica. Polymer as a waveguide material offers some advantages over inorganic glass such as silica, in some respects, however, low levels of signal loss i.e. high transparency of inorganic glass is desirable and preferred to polymer. Polymer waveguides are noted for low transparency, i.e. significant loss; polymer waveguides have a high coefficient of expansion and, associated with that a high (negative) thermo-optic co-efficient, and a low thermal conductivity. In contrast, inorganic glass has a high transparency, a high thermal conductivity, and a low (positive) thermo-optic coefficient. By combining polymer and glass, or fused silica in a structure or device and applying heat thereto, the refractive index difference between the two materials is greatly enhanced. Thus, if the two materials have a refractive index difference of approximately zero at ambient temperature, in the presence of an applied heat source to the polymer glass region, a refractive index difference increases.

This invention utilizes these differences in the two materials in a synergistic manner by providing a inorganic glass/polymer hybrid core structure that is highly advantageous. A suitable polymer for this application is polysiloxane elastomer.

Referring now to Fig. 16, an optical fibre 100 is shown, having a cleaved end 120 and having a region of polymer 140 applied to the cleaved end so as to form a core of glass and interrupted by a polymer region forming two contiguous sections. In a preferred embodiment the polymer is selected such that it has a same refractive index as the glass core of the optical fibre at an ambient operating temperature.

A resistive heating element 160 is formed around the polymer end. The temperature of the heater is controllable with an applied voltage and control circuitry. In Fig. 16 a small container 150 is shown that fits over the end 120 of the cleaved fiber 100. The container can be filled with photo or thermal curable monomers that are fluid. After the end 120 of the fibre is disposed into the container the monomers are cured to form a solid polymer which also serves as an adhesive. The heater 160 can be attached to the wall of the container. Alternatively the fiber end can also be attached to a planar substrate embedded in the cured monomers with the heating elements disposed onto the substrate close to the fiber end.

In operation, when light is launched into the optical fibre 100 toward the polymer 140 end, the light can be substantially absorbed, transmitted, or partially reflected depending upon the refractive index difference between the glass core and the polymer end. For example, if the refractive index of the polymer is slight higher than the glass, little or no light will be reflected. On the other hand, if heat is applied, and the refractive index of the polymer is lower than that of the glass core, some light incident upon the polymer 140 will be reflected; this effect is enhanced by an increase in the refractive index difference between the glass core and the polymer region.

Fig. 17 illustrates another example of a device 200 wherein two glass optical fibres 100a and 100b are disposed end-to-end, having a thin region of polymer 140 between the two waveguides. It is preferable to have as thin a region of polymer 140 as possible coupled between the two optical fibres while ensuring that the region is thick enough to provide the contrast in refractive index that is desired when heat is applied. There are several advantages to ensuring that the region is relatively thin; for example this allows the gap between the two optical fibres to be as small as possible, and less coupling loss results. It is estimated that the coupling loss resulting from having an air gap of 19 μm in air only due to diffractive spreading of the beam is approximately 0.2dB. However there is a significant loss in air due to Fresnel reflection. By disposing an index matched polymer in the gap would keep the losses to a minimum and confined essentially to diffractive

spreading losses. As with the previous embodiment described with reference to Fig. 16, the polymer disposed between the two fibres is heated to provide a refractive index contrast between the fiber cores and the polymer and to provide some reflectivity of a signal incident upon the polymer region. Although the fibres 100a and 100b are shown unconstrained for ease of understanding the invention, in practice the fibres would be securely held in a conventional manner, in a sleeve, or a v-groove holder or adhesively held to a package. In a preferred embodiment, the ends of the optical fibres are disposed in two ends of a capillary filled with the curable monomers. The gap is then adjusted by using conventional jigs such as those used in the production of GRIN rod components. Alternatively, a capillary can also be a V-groove (array) in a planar substrate, for instance an anisotropically etched groove in Si. The heaters can than be lithographically created onto this substrate. In this case also a single fiber can be disposed in the V-groove and secured by means of an adhesive while a gap can be created in the fiber by means of a dicing saw. The gap width can be adjusted by the selection of the dicing saw blade thickness.

Fig. 18 illustrates an optical network 300 having devices 200a through 200g similar to device 200 as described in Fig. 17 for providing status information about the network. Since device 200 is substantially wavelength independent, it is tolerant and highly suitable to a network having multiplexed channels. The optical network shown in this exemplary embodiment has several branches and within each branch is a device 200, which normally transmits light incident thereon. Notwithstanding, when a device 200 is switched on, some light incident thereon is reflected backwards to is source. For example, in a scenario where it is desired to know if Subscriber 140 is receiving an optical signal from the transmitter 160, device 200d is switched on by turning on the heater 160. A portion of the incident signal destined for subscriber 140 is reflected and detected at the input. Since essentially no reflection is received when the heater is switched off, and the path is in tact, switching on the heater provides a means of testing or verifying the integrity of the path to subscriber 140. Control signals required to switch on individual device 200a through 200g are not shown in this figure. Of course control signal could be

encoded within a signal to trigger a device, for example 200d to switch one for a short interval, however required additional detection and decoding circuitry would be required.

Fig. 19 illustrates an embodiment of the device shown in Fig. 17 wherein mode field expanded optical fibres 400a and 400b such as thermally expanded core (TEC) optical fibre is used. By using a TEC fibre, coupling efficiency can be enhanced.

The embodiments described heretofore have been related to the use of a polymer with one or more optical fibres, however, this invention is not limited thereto. For example in an alternative embodiment, a polymer region can be provided contiguous with a glass core in a waveguide chip by grafting polymer at an end or between two glass waveguides.

The grafting of planar polymeric waveguides is known and is described in a publication entitled Novel "serially grafted" connection between functional and passive polymer waveguides, by Watanabe et al Appl. Phys. Lett. 65 (10), 5 Sept. 1994, pp. 1205-1207 The process steps required to create inlay-structures are shown in the figures and begin with spin-coating a lower cladding layer 12 onto a silicon substrate 10 followed by coating the core polymer 14 as is shown in Fig. 1. This core layer is used to create parts to be grafted. Fig. 2 illustrates the application of metal structures 16 used as a mask for the grafting parts and realized onto lift off resist by evaporation of a metal layer, resist spinning and definition by photo-lithography. The grafting parts 18 are shown in Fig. 3 after reactive ion etching (RIE) to remove the unmasked core layer material. After a lift-off step to remove the metal mask, a second core layer 20 is spin coated. The remaining portion of the waveguide core is formed by this layer. Conventional etch-back planarization is performed to reach a flat surface. A planarization layer is spin-coated onto the second core layer 20 and then etched back until the preferred waveguide height is reached. The topography of the upper surface of the planarization layer is transferred to the underlying layer. In this manner a polymer stack with grafted parts and a flat surface is reached as shown in Fig. 4. After this, another metal structure 22 is defined onto lift-off resist, by evaporation of a metal layer, resist spinning and definition by photo-lithography with the final waveguide pattern as shown in Fig. 5. Fig. 6 illustrates

the waveguide consisting of grafted parts 18, 19 after reactive ion etching. Fig. 7 illustrates the polymer stack after a final spin-coat 24 of upper cladding is applied.

Although optical devices made of two different polymer cores such as the grafted cores described heretofore are useful in certain optical applications, it is believed that this structure can greatly be improved upon.

This invention relates to the provision of an optical waveguide having a core wherein a region of the core is a polymer material and wherein an adjacent contiguous region of the core of the waveguide is inorganic glass preferably silica. Since silica is highly transparent, and less attenuating than polymer materials, it is preferable in most instances to manufacture devices wherein the core is substantially made of silica, and wherein a much smaller lesser portion is made of polymer. Furthermore, many of the benefits of polymer can be utilized by using only a small amount of polymer in these devices. For example in an active device such as an optical switch, the switching region itself can be realized with a small polymer grafted insert. In temperature stable devices, where the advantageous combination of combining a core of polymer with a core of silica is provided, the ratio of polymer to silica or glass is about 1:10, hence only a small amount of polymer is required in many instances in smaller devices. Polymer silica hybrid core waveguides as described hereafter are particularly suitable in optical switch or in-line Bragg grating applications for a plurality of reasons. Since a polymer silica core hybrid waveguide can be provided wherein the refractive index is the same at ambient temperature, or at a predetermined temperature, gratings can be manufactured which are substantially transmissive at a particular temperature and which are highly reflective at other higher temperatures for predetermined wavelengths of light. Hence such an optical waveguide would act as a reflective (or forward coupling) filter when heat is applied and would act as if the grating was absent when the heat was removed. Instead of the multiple polymer silica sections that are used in the gratings, a single polymer section would act as a wavelength insensitive reflector when heat is applied and would act as if the reflector was absent when the heat was removed.

Thus, practicable, useful active and passive optical devices can be made from the waveguides in accordance with this invention.

Figs. 1 through 7 as shown relate to the formation of a hybrid grafted core section having two different polymer materials adjacent one another forming the core of the waveguide. This process can be extended to yield a hybrid silica/polymer core in accordance with this invention. Referring now to Figs. 1 through 7 again, the initial base layers 12 and 14 are now made of silica; these layers can be created by flame hydrolysis deposition (FHD) process or a chemical vapour deposition (CVD) process; these layers precede polymer layers because they fabricated at temperatures well above the degradation temperature for polymers. Initially the lower silica cladding layer 12 is deposited onto the silicon substrate 10, followed by the silica core layer 14. This is illustrated in Fig. 1 Channel waveguide core sections will be etched out of the core layer by means of reactive ion etching (RIE) in CHF_3, Ar gas mixtures using a Cr mask. This mask 16 is created by Cr layer sputtering onto the core layer followed by standard photolithographic resist patterning and wet chemical etching. Hence openings for the polymer channels section to be disposed are provided as is illustrated in Fig. 2. After RIE, the mask is removed by a wet chemical etching process and the silica grafting parts 18 are ready for polymer overcoating as can be seen in Fig. 3 .

This is illustrated in Fig. 4 where a solution of cross-linkable polymer for the core sections has been spin-coated onto the wafer to embed the remaining silica core sections 18 in the core polymer 20. Dependent on the polymer that is used, thermal or photocuring is used to make the polymer layer insoluble. Additional cured polymer layers can be deposited over this layer to further planarize the surface. The polymer surface is then etched down to the upper core surface using RIE with O_2. A continuous Ti mask pattern 22 for the hybrid channel waveguide is formed onto this surface by means of a standard photolithographic resist patterning followed by dry etching using RIE with SF_6.This is shown in Fig. 5 The Ti is evaporated onto a photoresist layer that is spincoated first onto the surface. Fig. 6 shows the continuous hybrid channel 18+19 that is created by polymer etching using O_2-RIE. The mask pattern is removed by a lift off procedure. Finally a

polymer upper cladding layer 24 having a refractive index that is lower than the refractive index of the polymer core sections is spin-coated over the hybrid channel waveguide structure as illustrated in Fig. 7. After curing it forms an insoluble upper cladding layer. The final waveguide is formed of core sections of silica 18 and adjacent core sections 19 of polymer.

Fig. 8 to 11 show an alternative process that begins from silica channel waveguides 34 including the upper silica cladding 3 (Fig. 8). Sections for the polymer core are provided by etching out the silica down to the lower silica cladding using a metal mask (Fig.9) to make grafting gaps in the silica core by RIE (Fig. 10). The gaps are filled first with the core polymer by spincoating and curing. This polymer is then etched down by RIE with O_2 to the upper core interface. This process can be carried out without the use of a mask , because the silica is not etched in the RIE process for the polymer. A polymer cladding is applied thereafter (Fig.11).

Referring now to Figs 12a through 12d the etch back principle is illustrated. To successfully etch back the planarization material has to have the same etch speed as the core or grafting material. The initial situation is a layer stack which is built up to the planarization layer as show in 12a. When the etch rate of the planarization material v_p is larger than the etch rate of the core materials v_c a bump will remain as illustrated in Fig. 12b. When the etch rate of the planarization material is smaller than the etch rate of the core material a dent can arise as shown in Fig. 12c. Preferably as shown in Fig. 12d, $v_p = v_c$.

Fig. 13 shows in a prior art European patent application EP 0797113A1 in the name of Bosc et al. a planar waveguide having silica core and a polymer cladding region. Although there are advantages to such a structure, in contrast the instant invention provides a planar optical waveguide that provides an entirely new class of optical devices.

This invention provides control of and within the core of a waveguide itself.

Hence by using these two very compatible materials having significantly different properties within a core of an optical waveguide, a host of new devices are practicable; devices which can route, switch, multiplex and modify channels or wavelengths of light; devices essential for optical communications. The core of the waveguide need not be confined to small dimension typically associated with single mode propagation of light; core dimensions may in fact be considerably larger, for example for use in applications such as multimode interference devices.

Referring now to Fig. 14, a core of an optical waveguide is shown, in accordance with this invention, having a polymer portion 12, grafted between two silica sections 10. Of course a suitable cladding is required (not shown) around the waveguide core in Fig. 14 to ensure that light is confined within the core. Although the polymer portion 12 and silica sections 10 are adjacent and contiguous to one another in a longitudinal sense, serially one portion after the other, this invention is not confined to longitudinal contiguous sections or portions of silica and polymer within a core of a waveguide. For instance, in Fig. 15 a core is shown having two contiguous portions of silica 40 and polymer 42, wherein there are no longitudinal abutting portions.

Of course numerous other embodiments can be envisaged without departing from the spirit and scope of the invention. For example, in an alternative an attenuator that does not reflect can be provided by angling the end facets of the optical fibre and varying the refractive index of the polymer therebetween.

Claims

What is claimed is:

1. An optical device comprising:
an optical fibre having a glass core and a cladding, the optical fibre having at an end thereof a region of polymer optically and physically coupled with the glass core, and, means for varying the refractive index of the polymer in dependence upon a control signal.

2. An optical device as defined in claim 1, further comprising a second optical fibre coupled with the region of polymer, so that that two optical fibres are optically coupled with one another having the region of polymer therebetween

3. An optical device as defined in claim 2, wherein the optical fibre has a mode field expanded core.

4. An optical device as defined in claim 2, wherein the means for varying the refractive index is a heater.

5. An optical device as defined in claim 4, wherein the device is operable in at least a first mode and a second mode, wherein in the first mode in the absence of heat applied to the polymer region, light transmitted into one of the fibres, substantially propagates through the polymer region unimpeded to couple with the second optical fibre, and wherein in the second mode of operation wherein in the presence of heat, the refractive index of the polymer lessens and light transmitted into one of the optical fibres is at least partially reflected backwards.

6. An optical device as defined in claim 4, wherein the device is operable in at least a first mode and a second mode, wherein in the first mode in the absence of heat applied to

the polymer region, light transmitted into one of the fibres, substantially propagates through the polymer region unimpeded to couple with the second optical fibre, and wherein in the second mode of operation wherein in the presence of heat, the refractive index of the polymer lessens and light transmitted into one of the optical fibres is at least partially reflected into a direction that does not couple to a propagating mode of either fibre.

7. A device for allowing light to propagate therethrough in a first transmissive mode of operation and for at least partially reflecting light launched therein in a second at least partially reflecting mode of operation comprising:
a first and a second optical fibre;
a polymer region disposed therebetween and coupled with an end of each of the first and second optical fibres, and
means for controllably changing the refractive index of the polymer region to switch between the first mode of operation and the second mode of operation.

8. A device as defined in claim 7 wherein the means for controllably changing the refractive index is a heater thermally coupled with the polymer region.

9. A device as defined in claim 8, wherein the polymer has a negative thermo-optic coefficient and wherein the first and second optical fibres have cores with positive thermo-optic coefficients.

10. A device as defined in claim 9 wherein the optical fibres have cores comprising silica.

11. A device as defined in claim 10, wherein inwardly facing ends coupled with the polymer region are mode field expanded ends.

12. An optical network comprising a plurality of the devices defined in claim 10 for use in providing information related to the network.

13. An optical device as defined in claim 7, wherein the first and second optical fibre ends having mode field expanded cores.

14. An optical device as defined in claim 7 wherein the device is an optical attenuator.

15. An optical device comprising:
a first optical waveguide having a glass core and a cladding, the first optical waveguide having at an end thereof a region of polymer optically and physically coupled with the glass core, and,
means for varying the refractive index of the polymer region in dependence upon a control signal.

16. An optical device as defined in claim 15, further comprising a second optical waveguide having a core directly coupled with and in contact with the region of polymer.

17. An optical device as defined in claim 16, wherein the first optical waveguide, and the second optical waveguide and the polymer region disposed therebetween form a contiguous core, covered by a common cladding.

1
Core
Lower cladding
substrate

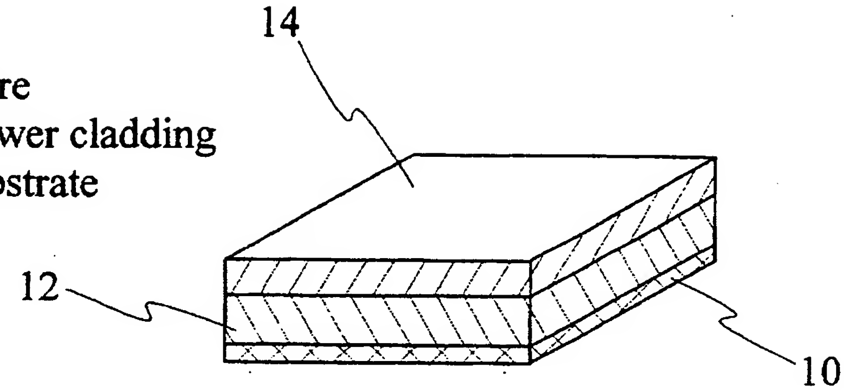


Fig. 1

2
Metal mask
grafting parts

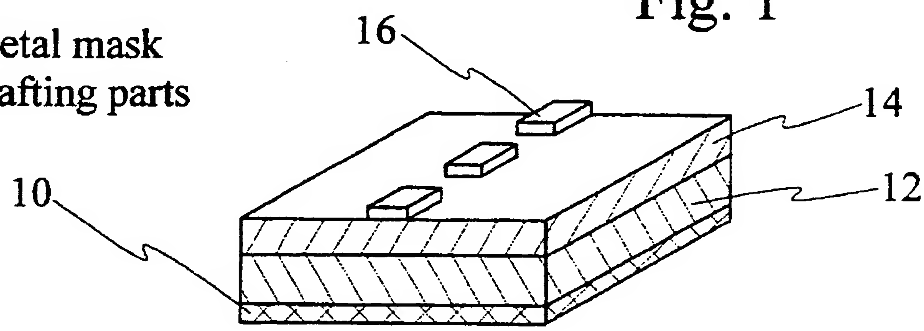


Fig. 2

3
Grafting parts

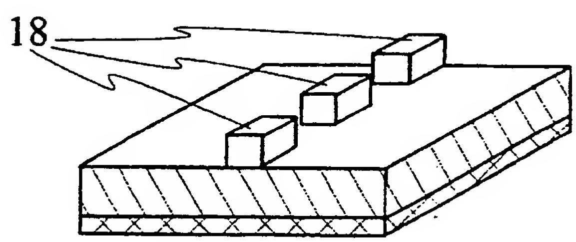


Fig. 3

4
Stack with
grafting parts

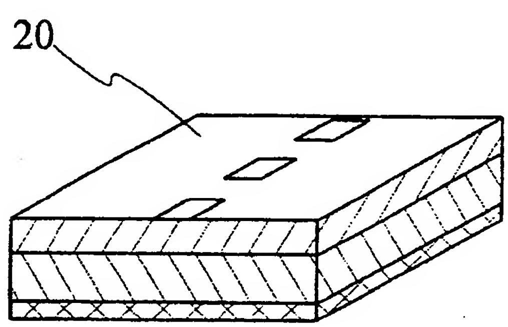


Fig. 4

5
Metal mask
waveguide

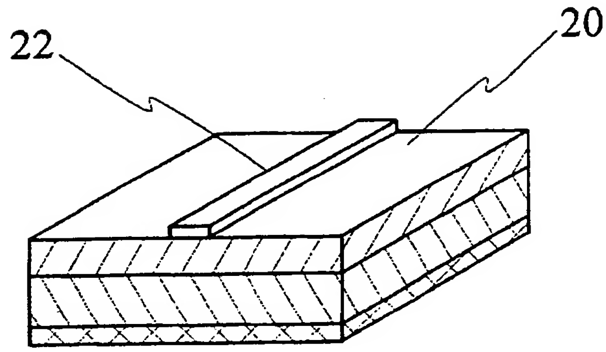


Fig. 5

6
Waveguide with
grafting parts

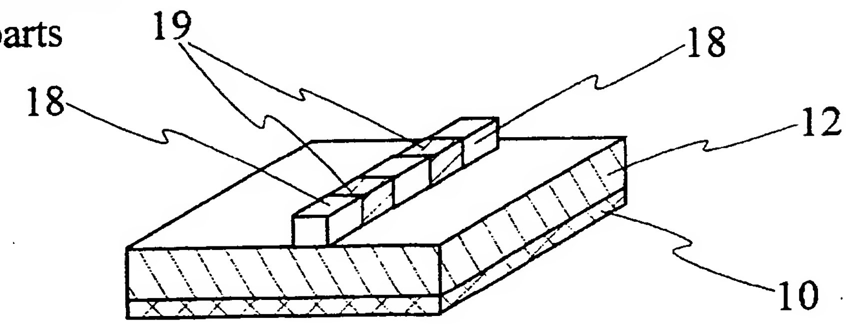


Fig. 6

7
Upper cladding

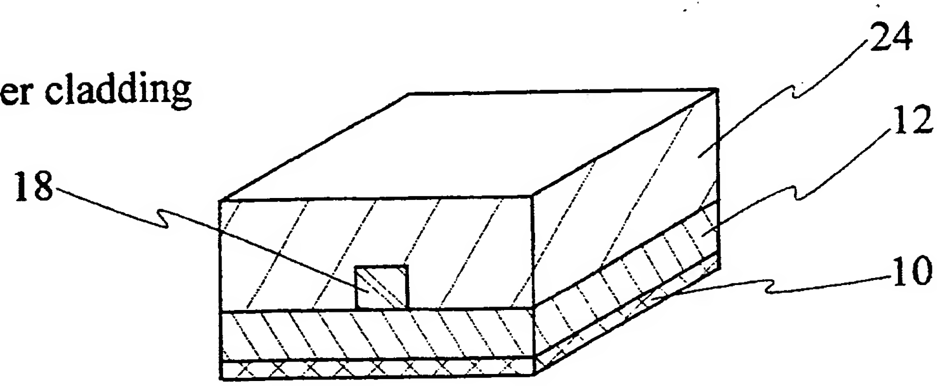


Fig. 7

1
Core
Lower cladding
substrate

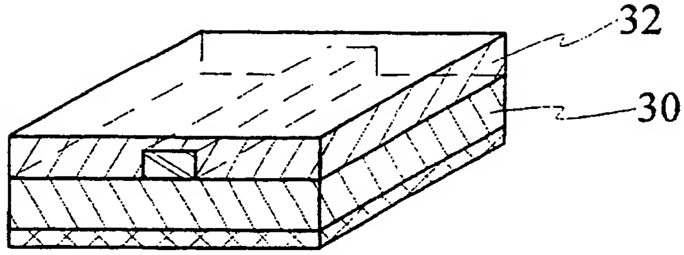


Fig. 8

2
Metal mask
grafting gaps

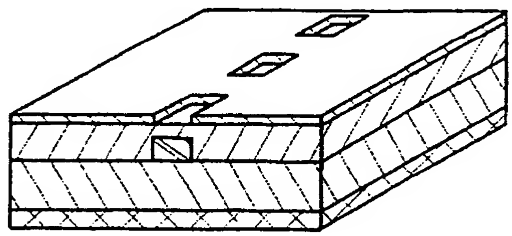


Fig. 9

3
Gaps for
grafting

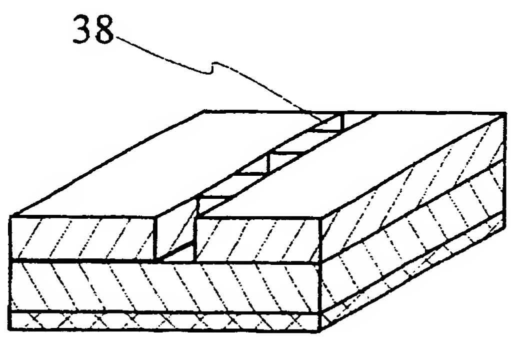


Fig. 10

4
Upper cladding

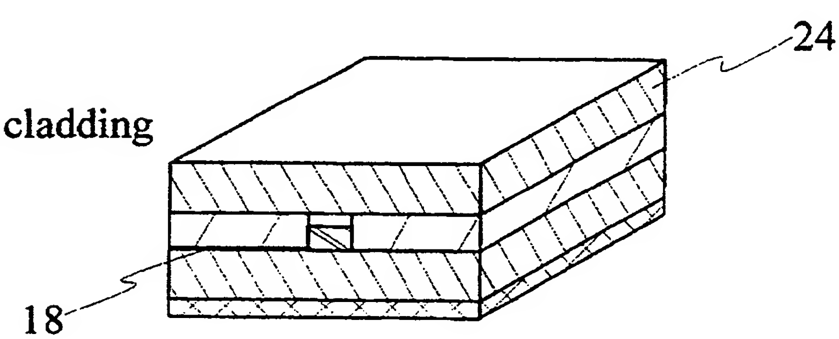


Fig. 11

1

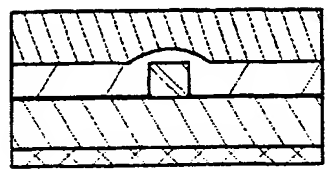


Fig. 12a

$V_P > V_C$

2

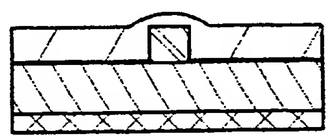


Fig. 12b

$V_P < V_C$

3

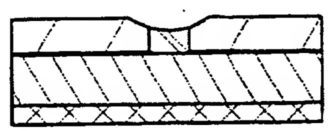


Fig. 12c

$V_P = V_C$

4

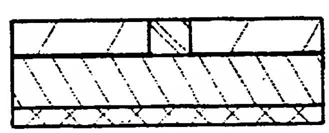


Fig. 12d

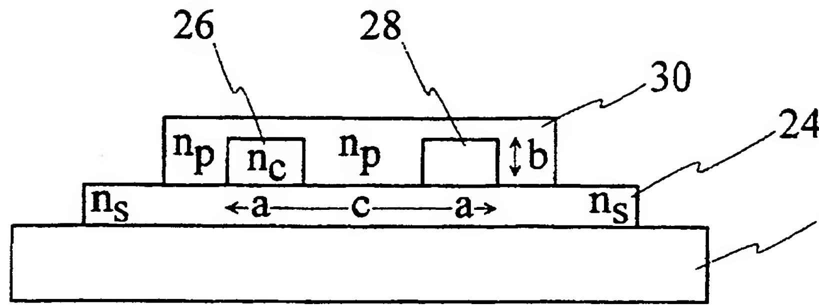


Fig. 13

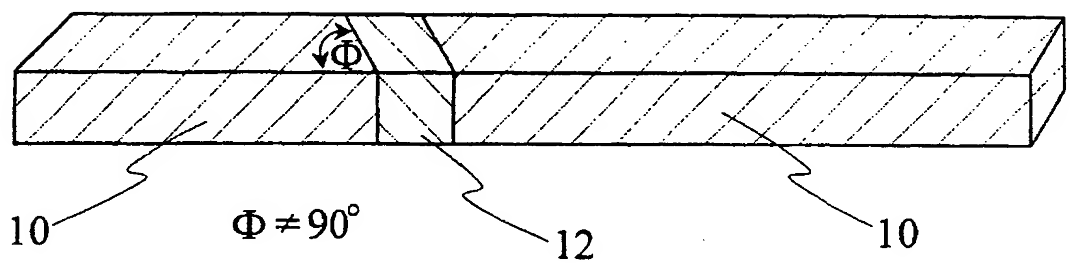


Fig. 14

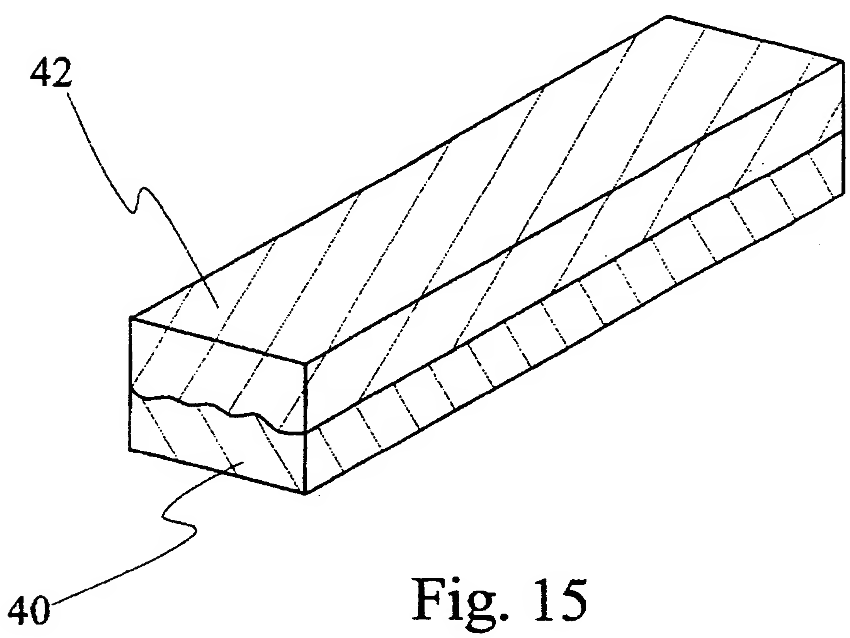


Fig. 15

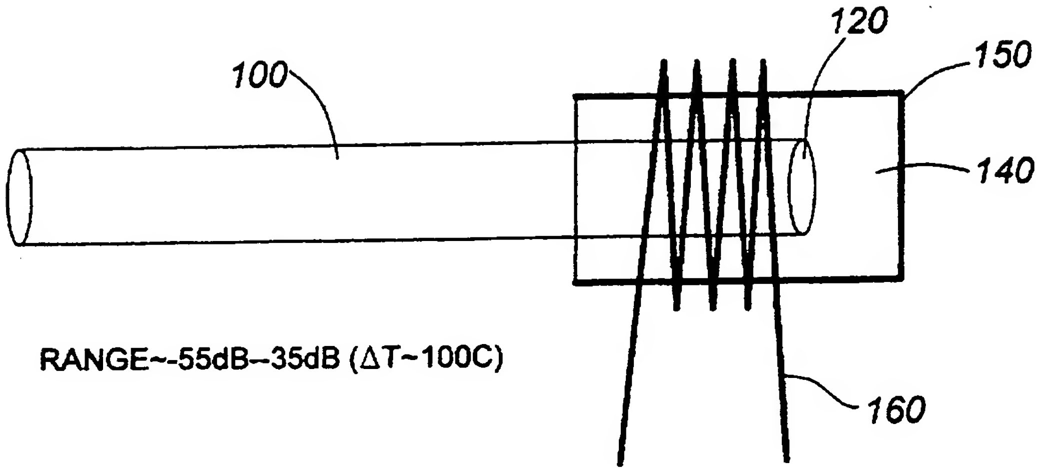


FIG. 16

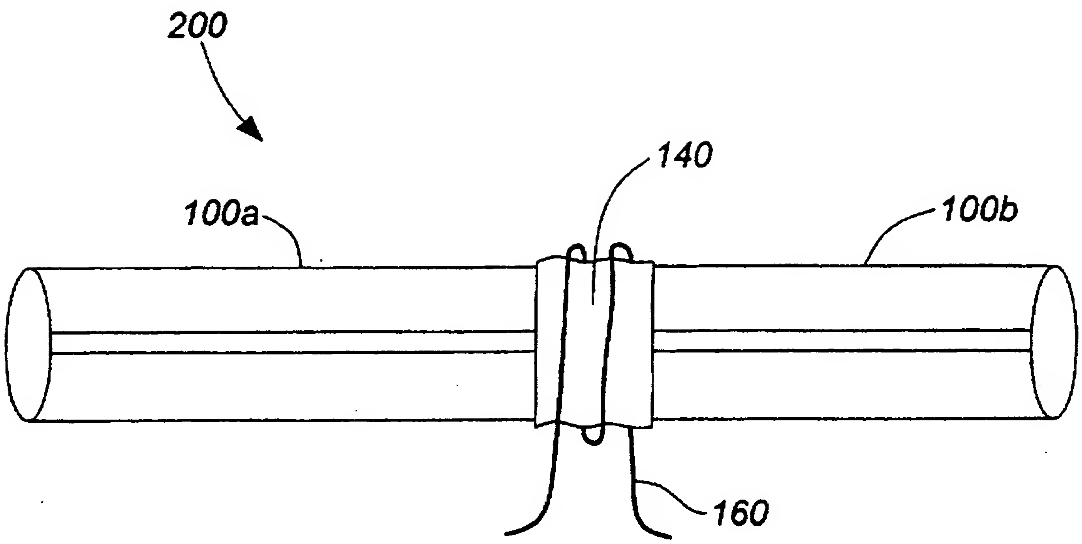


FIG. 17

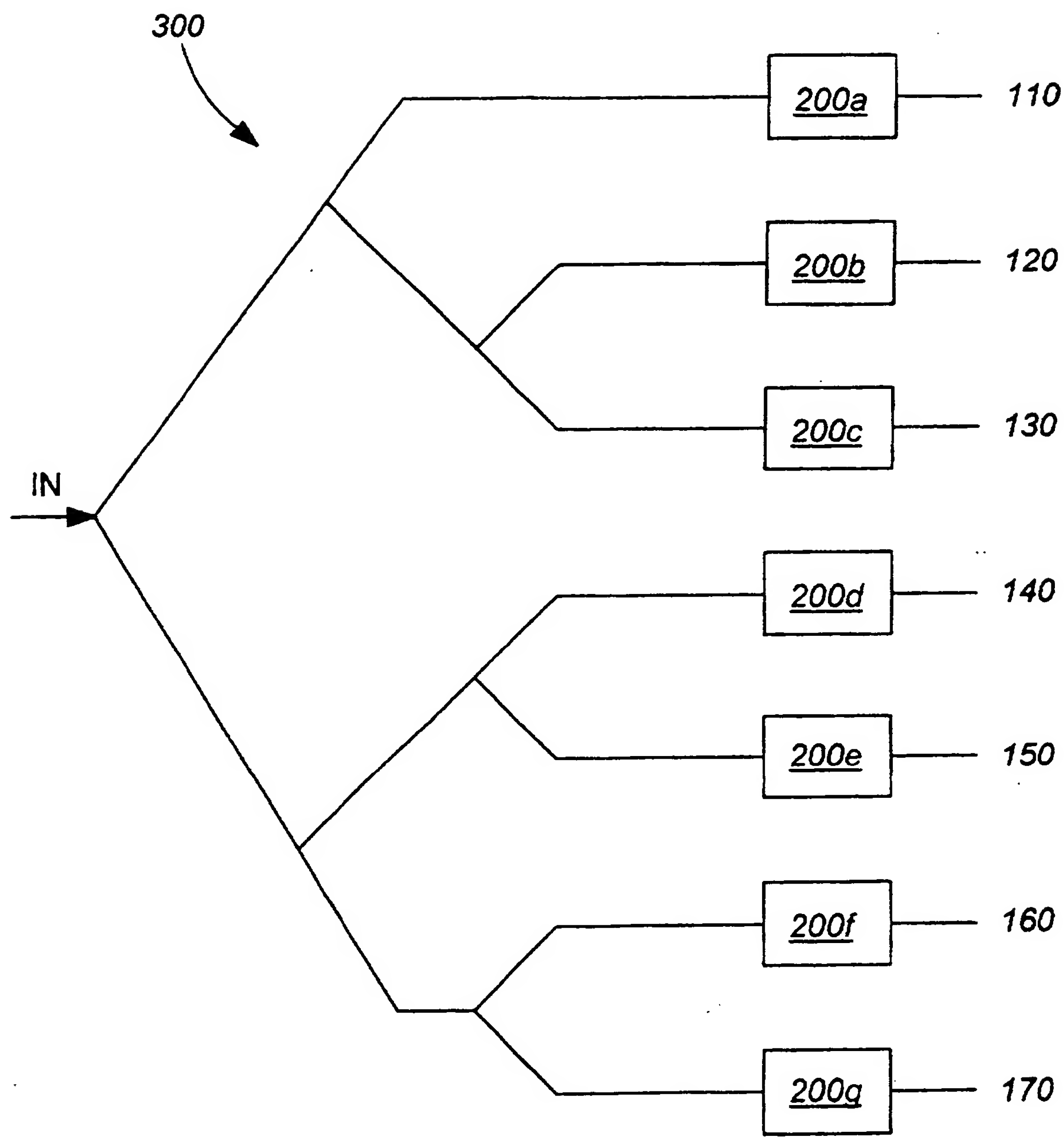

300
IN
200a
200b
200c
200d
200e
200f
200g
110
120
130
140
150
160
170

FIG. 18

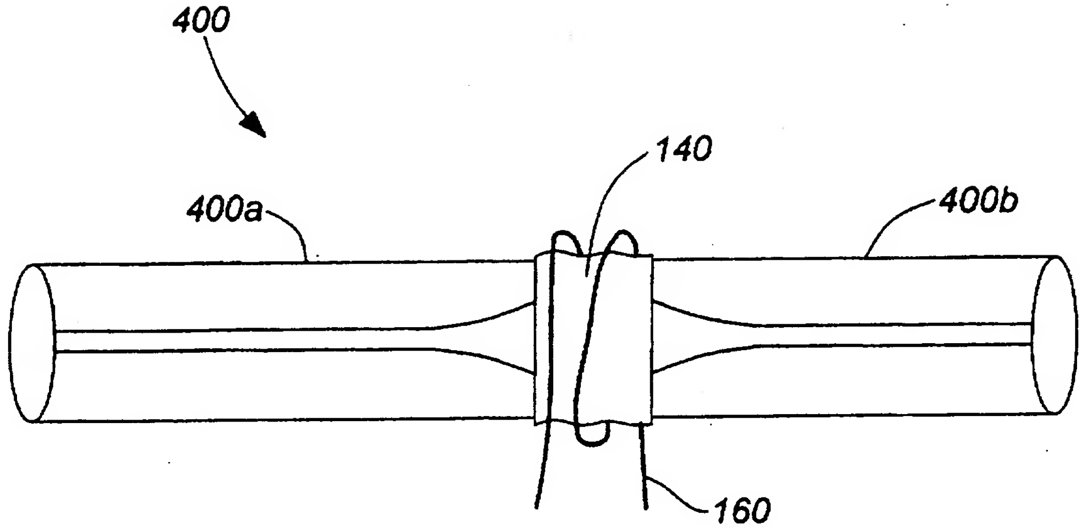


FIG. 19